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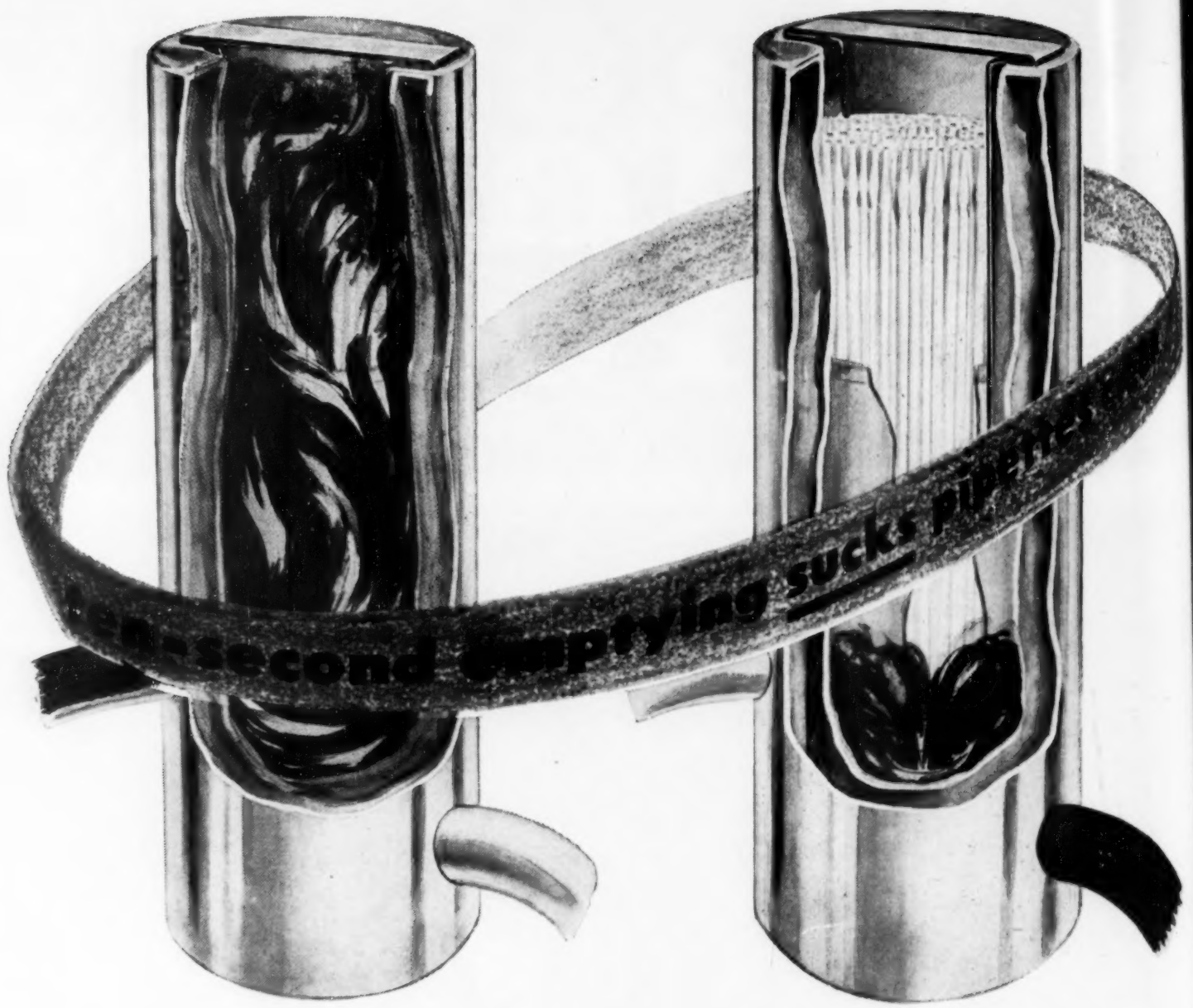
(See page 441)



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Nuclear Magnetism in Relation to Problems of the Liquid and Solid States

E. M. Purcell

Lyman Laboratory of Physics, Harvard University

THE MAGNETIC BEHAVIOR OF MATTER in the bulk—paramagnetism, diamagnetism, and ferromagnetism—can be traced to the electronic structure of the atoms of which the matter is composed. The *electron,* in short, is the cause of ordinary magnetism. But the electron is not the only magnetic constituent of most substances, for many atomic *nuclei* have certain magnetic properties. Although the magnetic effects to which these nuclear properties give rise are too feeble to be observed under most circumstances, it has been possible to devise techniques which bring them into prominence. From these experiments in nuclear magnetism one learns more about the nucleus, and, since the most active frontier in physics lies at the nucleus, such information is highly prized. In quite another direction, however, a line of approach is opened to certain features of the structure of liquids and solids which prove to be involved in an interesting and unusual way in the manifestations of nuclear magnetism.

It is the latter aspect of nuclear magnetism that I propose to survey in this article, after providing an introduction to the magnetic properties of nuclei and to the phenomenon of resonance upon which the experimental method depends. "Survey" is perhaps too ambitious a term, for any attempt to predict the ultimate extent or importance of this new field must be renounced at the outset.

Nuclear Spins and Magnetic Moments

In addition to their more familiar properties of mass and electric charge, many atomic nuclei possess intrinsic angular momentum, or "spin," and magnetic moment; that is to say, the nucleus behaves like a spinning top with a magnet embedded along its axis. It is natural to seek the origin of nuclear magnetism in the motion of the positive electric charge of the nucleus; charge in motion is the same as electric current, and electric currents produce magnetic fields. We are thus led to regard the proton, for example, as a positively charged sphere spinning with a certain angular momentum and equivalent, in its magnetic properties, to an infinitesimal magnetic dipole. Although such a view eventually proves inadequate, it will serve very well as a basis for our discussion.

The intrinsic angular momentum of a nucleus is specified, in units of $h/2\pi$ (h = Planck's constant), by the number I, which is either integral or half-integral. The quantity $Ih/2\pi$, to be more explicit, is the maximum component of the angular momentum vector measured along a selected direction. The magnetic moment, μ (the strength of the nuclear dipole), is conveniently expressed as a multiple of a unit called the ***nuclear magneton*** and defined as $eh/4\pi Mc$, where e is the electronic charge; M, the mass of the proton; and c, the speed of light. Nuclear magnetic moments are, in general, of the order of magnitude of one nuclear magneton. The intrinsic magnetic moment of the *electron,* by contrast, is $eh/4\pi mc$, where m is the electronic mass. Thus, nuclear magnetic moments are roughly 1,000 times smaller than electronic moments.

The spin number, I, of a given nuclear species and, so far as we know, the magnetic moment, μ, are permanent, sharply defined characteristics of the nucleus, not to be altered by any means short of raising the nucleus to an excited state, a comparatively violent process with which we shall not be concerned.

The properties of spin and magnetic moment were first attributed to nuclei in 1924, by Pauli, to account for the so-called *hyperfine* structure of lines in the spectra of certain elements. Such a line, analyzed with a spectrograph of high resolving power, had been found to consist of a very closely spaced group of lines, or multiplet—an effect which could be explained by taking account of the interaction of the nuclear magnet with the magnetic fields arising from the motion of the electrons in the atom. The recognition by Goudsmit and Uhlenbeck of the intrinsic spin and magnetic moment of the electron itself, and the subsequent rapid progress in the correlation of atomic spectra with atomic structure, opened the way to a complete quantitative interpretation of hyperfine structure. The magnitude of the nuclear angular momentum and magnetic moment could, in turn, be deduced from the results of hyperfine structure measurements.

To determine the nuclear magnetic moment by this means one must measure the separation in frequency of exceedingly closely spaced spectral components. Very precise values can seldom be obtained, despite the remarkable advances in high-resolution spectroscopy which this challenging problem has called forth. The nucleus is an extremely feeble magnet, and this is the cause of the difficulty. The energy differences

involved in the interaction of the nuclear magnet with the surrounding electrons, or with an applied magnetic field, are usually not larger than 10^{-20} to 10^{-18} ergs. According to the Bohr relation, $\Delta E = h\nu$, the corresponding frequencies lie in the band of ordinary radio frequencies or at most, in a few extreme cases, in the region of centimeter-wave lengths.

The possibility is thereby suggested of measuring such weak interactions directly, by detecting the absorption or emission of waves of radio frequency. Just this has been done in the celebrated molecular beam experiments of Rabi and his students at Columbia (*7*). By this form of radio-frequency spectroscopy,[1] augmented in some cases by the more recent—although in many respects more conventional—radio-frequency methods to be described presently, the magnetic moments of nearly 40 nuclear species have been determined with high precision. Hyperfine structure measurements in the optical region have established the spins and, at least approximately, the magnetic moments of about 35 additional species. There are left, among the stable nuclei which would be expected to possess magnetic moment, more than 40 which are still unmeasured.

The spins and magnetic moments of several nuclear species are listed in Table 1. Most of the entries in this abbreviated table originated in the Columbia molecular beam laboratory. The magnetic moment of the neutron deserves special mention. This was first measured by Alvarez and Bloch, at Berkeley, by an ingenious adaptation of molecular beam principles; the value listed was obtained more recently by Arnold and Roberts, at the Argonne Laboratory, by a refinement of the same method. The precision with which nuclear magnetic moments can now be compared is not fully displayed in the tabulations. For example, Bloch has recently redetermined, at Stanford, the ratio of the magnetic moment of the proton $_1H^1$ to that of the deuteron $_1H^2$, obtaining 3.257195 ± 0.00002. The magnetic moment of the triton $_1H^3$, a novel particle still unavailable in most laboratories, is equally well established.

TABLE 1

NUCLEAR SPINS IN UNITS OF $h/2\pi$, AND NUCLEAR MAGNETIC MOMENTS IN UNITS OF THE NUCLEAR MAGNETON, μ_0, OF THE NEUTRON, THE TRITON, AND THE STABLE NUCLEI THROUGH O^{16}*

Nucleus	I	μ/μ_0	Nucleus	I	μ/μ_0
$_0n^1$	1/2	−1.910	$_4Be^9$	3/2	−1.176
$_1H^1$	1/2	2.7896	$_5B^{10}$	1	0.598
$_1H^2$	1	0.8564	$_5B^{11}$	3/2	2.687
$_1H^3$	1/2	2.9756	$_6C^{12}$	0	0
$_2He^3$	1/2	?	$_6C^{13}$	1/2	0.701
$_2He^4$	0	0	$_7N^{14}$	1	0.403
$_3Li^6$	1	0.8214	$_7N^{15}$	1/2	0.280
$_3Li^7$	3/2	3.2535	$_8O^{16}$	0	0

* The sign of the magnetic moment refers to the polarity of the nuclear dipole with respect to the direction of the angular momentum vector.

The table discloses no obvious systematic variation of the magnetic moment, μ, with charge and mass number. So far as the spin is concerned, two general rules can be stated: (1) The spin number, I, is an odd or an even multiple of $\frac{1}{2}$ as the mass number, A, is odd or even; this is a direct consequence of the half-integral spins of the nuclear constituents, the neutron and the proton. (2) A nucleus that contains an even number of protons and an even number of neutrons, such as $_8O^{16}$, or $_{38}Sr^{88}$, has zero spin and moment; this is an empirical rule to which no exception has yet been discovered. Further than this, the task of relating quantitatively the magnetic moments of nuclei to the details of nuclear structure remains one of the larger problems of theoretical nuclear physics. A beginning has been made among the light nuclei (*2*), but beyond the limits of Table 1, roughly, even an approximate theory is lacking. The depth of the problem, as well as the inadequacy of the spinning, charged sphere as a model of the nucleus, is suggested by the fact that the neutron, an uncharged "elementary" particle, has a magnetic moment!

Fortunately, we need not concern ourselves here with the details of nuclear structure. In the experiments to be described, the nucleus can be regarded merely as a carrier of magnetic moment and angular momentum to which the rules of quantum mechanics apply. We shall be interested in the interaction of the magnetic nucleus with its surroundings and with an externally applied magnetic field. It will not seriously restrict the discussion if we confine our attention to a single nucleus, the proton, which has, according to Table 1, the intrinsic angular momentum $\frac{1}{2}(h/2\pi)$ and a magnetic moment amounting to 2.7896 nuclear magnetons.

Resonance Absorption

The emission or absorption of light by a free atom takes place in accordance with the resonance condition which quantum theory permits us to express in the following way: The possible states of an isolated atom include a sequence of discrete states sharply defined with respect to energy; a transition of the system from one of these states to another, differing in energy from the first by ΔE, is accompanied by emission (or absorption) of light of the frequency $\nu = \Delta E/h$ (h = Planck's constant).

Consider, for the moment, a free proton in a magnetic field of strength H_0. Ignoring the translational

[1] The rapidly growing field of radio-frequency and microwave spectroscopy, which has applications much broader than the scope of the present article, has been surveyed by Roberts in *Nucleonics*, October 1947.

grees of freedom, which are here irrelevant, this ple system will be found in one of two possible tes which differ in the orientation of the spin axis the proton with respect to the magnetic field. That the component, in the direction of the magnetic ld, of the angular momentum vector can assume her of the values $+h/4\pi$ and $-h/4\pi$. (For a par- e of spin I there are $2I+1$ possible states, or spin entations.) The two states differ in energy, for component of nuclear magnetic moment in the ection of the field is $+\mu$ in one case and $-\mu$ in the er. In fact, the difference in energy is just $2\mu H_0$, work that would be required to reverse the direc- of a magnet of strength μ which had originally aligned with a field H_0. The two states will be oted by (+) and (−), the (−) referring to the state higher energy in which the nuclear magnet is ected counter to the magnetic field. Actually, the axis of the nucleus lies in neither case parallel to direction of field H_0, but is tipped at a consider- angle and precesses about the direction of the ld, like the axis of a tilted top. This does not com- cate matters, for it is only the components of spin magnetic moment parallel to H_0 which concern us, it is just these components which are specified I and μ.

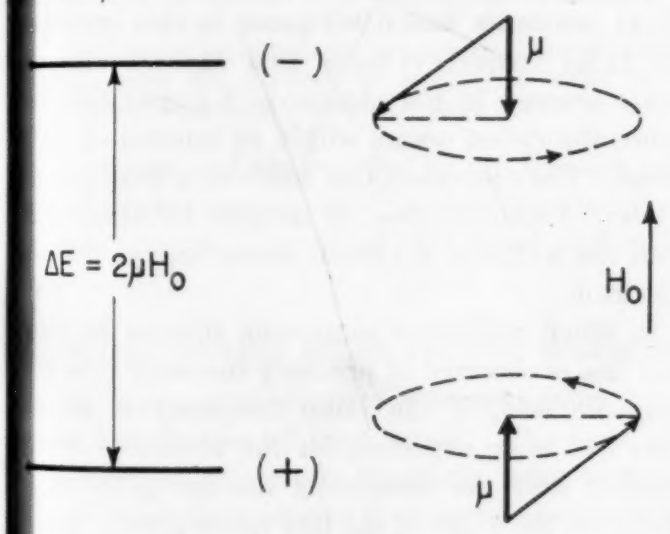

FIG. 1. The two energy states of a proton in a mag- tic field, H_0. The energy levels are drawn at the left.

The situation is illustrated in Fig. 1, in which the rgy level scheme appears. By exposing the system radiation of the proper frequency, it should be pos- to bring about a transition from one of the two tes to the other, with the consequent absorption of quantum of energy, in a (+) → (−) transition, or ission of a quantum, in a (−) → (+) transition. the former case, *resonance absorption* will have urred; the latter process is usually called stimu- ed emission, although, as it is the exact counterpart the former process, it might well be called reso- nce emission. For a proton in a magnetic field, H_0, 10,000 gauss, the resonance frequency, computed from $\nu = \Delta E/h = 2\mu H_0/h$ turns out to be about 41 megacycles/sec. The radiation required is therefore a radio wave, or, since only the magnetic field of the wave would be effective anyway, merely an oscillating magnetic field such as one might make by passing a radio-frequency current through a suitable coil.

Transitions of the sort described are the basis of the magnetic resonance method of molecular beams. The nuclei involved are located in electrically neutral molecules—a bare proton would be unmanageable for fairly obvious reasons. The problem is not seriously complicated by the presence of the surrounding constituents of the molecule. The molecule itself moves through a highly evacuated chamber and remains exceptionally *free* during its exposure to the radio-frequency oscillating field. It is therefore not surprising that sharply defined resonance effects can be observed. It will be recalled that one of the conditions essential for obtaining sharp lines in ordinary spectroscopy is that the emitting atoms occupy a region of relatively low pressure. The frequency of atomic collisions sets a limit on the lifetime of an excited state and hence (a familiar illustration of the uncertainty principle) limits the precision with which the energy of such a state can be specified, with a consequent broadening of the observed spectral line. This "collision broadening" becomes more pronounced as the pressure is increased until eventually the line structure of the spectrum is obliterated and we observe the continuous emission spectrum characteristic of an incandescent solid.

It might be expected that even lower pressures would be necessary for successful radio-frequency spectroscopy, which is concerned with extremely small energy differences. Low pressures are indeed necessary wherever atomic or molecular states are involved, a pressure as low as 10^{-5} atmospheres being required to reduce the width of a spectral line to 100 kilocycles/sec. The nucleus, however, occupies a uniquely isolated and protected position in the interior of the atom. More important, the states (+) and (−) in Fig. 1 can be perturbed only by *magnetic* fields, and in the majority of substances the electrons, which would otherwise cause strongly perturbing magnetic fields, are paired off in such a way that their net magnetic effect is zero. For this reason it has been possible to observe sharply defined resonance absorption, due to transitions of the type (+) → (−), in ordinary solids and liquids containing magnetic nuclei.

When such a substance—a drop of water, for example, or a lump of paraffin—is placed in a strong magnetic field, it can be regarded in first approximation as a mere collection of a large number of protons, for each of which the two energy states, (+) and (−), are available. With the application of a weak

radio-frequency magnetic field, oscillating at precisely the frequency of resonance, protons which were in the (+) state will make transitions to the (−) state and *vice versa*. The *vice versa* is important; in fact, the "up" and "down" transitions are induced with *equal probability,* and if the protons were initially equally divided between the two states, no *net* absorption of energy can occur. If the resonance effect is to be detectable, an inequality of the population of the two levels must be established. This will come about if the magnetic nuclei can transfer energy to, and come into thermal equilibrium with, their surroundings, for in thermal equilibrium the lower of the two energy levels will be favored with the larger population. At any easily attainable temperature the excess in the lower state is very slight; the ratio of the number of nuclei in the upper state to the number in the lower state is the well-known Boltzmann factor, $e^{-h\nu/kT}$, which, for $\nu = 40$ Mc/sec and $T = 300°$ K, is 0.9999934. It is upon the fractionally minute surplus of nuclei in the lower state that the observed effects entirely depend.[2] We shall inquire later into the means by which thermal equilibrium is established, thereby discovering a rather surprising situation. At present we shall assume that it can be attained somehow, and turn to the detection and interpretation of nuclear resonance absorption.

The method of observation is extremely simple in principle. Approximately 0.5 cc of water (for example), contained in a glass tube, is surrounded by a coil consisting of a few turns of copper wire. The coil is connected into a radio-frequency bridge circuit which is excited by an oscillator at, say, 40 Mc/sec. The coil with its water "core" is located within the field of a strong magnet. When the resonance condition is attained by adjustment of the frequency or of the strength of the magnetic field (usually the latter is easier) the absorption of energy by the protons in the water is manifested as a change in the apparent resistance of the coil. Because the effect to be detected is extremely feeble, the apparatus is actually more elaborate than the above description might suggest. However, a full description of the experimental technique, which can be found elsewhere (*5*), is not necessary for the present discussion.

The method outlined is essentially that used in the first observation of nuclear magnetic resonance absorption at Harvard in 1946 (*10*). At the same time and independently, Bloch, Hansen, and Packard, at Stanford, demonstrated the closely related phenomenon which Bloch has named *nuclear induction* (*3, 4*). The

[2] Another consequence of the surplus in the lower state is that the sample is feebly magnetized; that is, it displays static paramagnetic susceptibility. In a remarkable experiment performed in Russia in 1937, Lasarev and Schubnikov succeeded in detecting the paramagnetism caused by the protons in solid hydrogen, at 2° K.

two methods take advantage of somewhat differe manifestations of the same fundamental process; th may be areas of investigation where one or the ot is preferable, but both are coming into general use.

The resonance absorption by protons in water displayed in Fig. 2, a reproduction of an oscilloscc

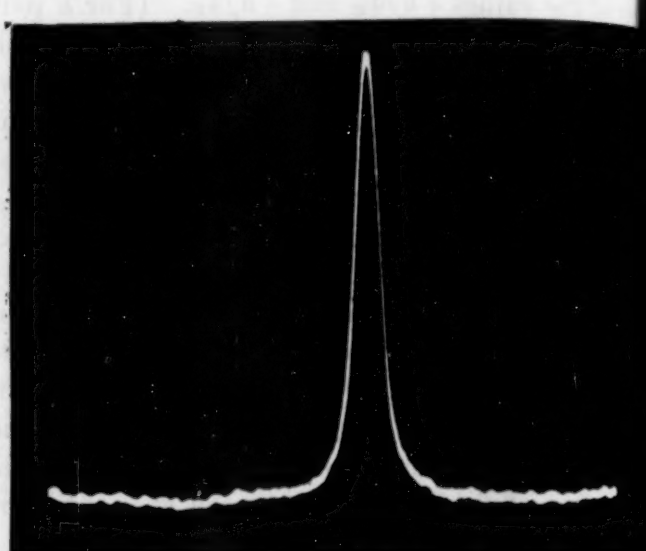

FIG. 2. Resonance absorption by protons in wate recorded on an oscilloscope.

trace obtained while sweeping through the resona line by varying the magnetic field, H_0. The value H_0 at resonance was 6,940 gauss in this experim the radio frequency being 29.5 Mc/sec. The t range covered in the picture is 2 gauss; thus, r nance absorption occurs within an interval of only gauss. The equivalent line width on a frequency s is about 1 kilocycle/sec, or roughly 10^5 times sma than the width of a typical sharp line in the vis spectrum.

In other substances containing protons an abs tion line is observed at precisely the same value of magnetic field, if the radio frequency is the s This was to be expected, for the resonance condi involves only the specifically nuclear property, However, the *width* of the line varies greatly from substance to another. The proton resonance in for example, is found to be 20–50 times as wide and correspondingly weaker than, the resonance sh in Fig. 2. In some crystals even more striking eff are observed. The proton resonance line develop more complicated shape, or even breaks up into eral more or less well-resolved components. A typical examples are sketched in Fig. 3, beginning the intense narrow line which is observed in water in many other liquids. The peak intensity of the sorption is inversely related to the line width, things being equal; the quantitative examination the broad, and therefore weak, lines illustrated Fig. 3 (b, c, d) calls for the utmost refinement in perimental technique.

ese effects are not to be explained in terms of ar properties alone, but are connected with the rbing magnetic fields which originate in the im- ate surroundings of a given hydrogen atom and

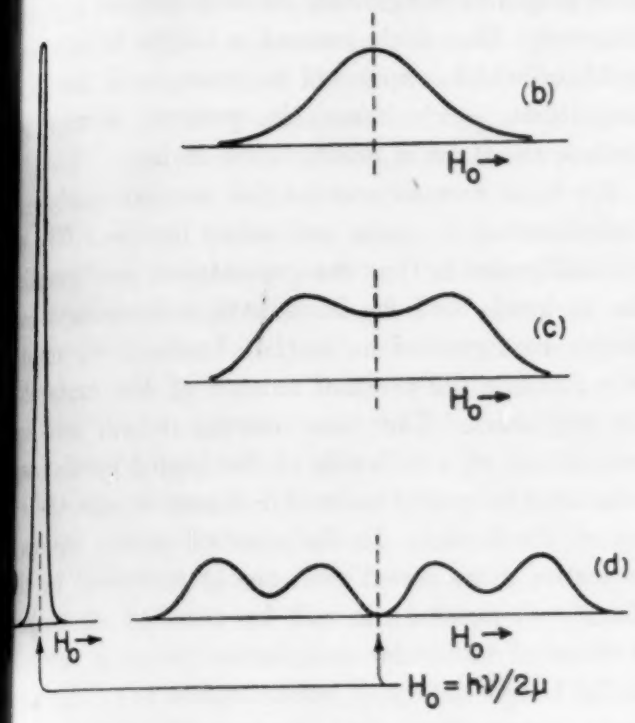

FIG. 3. The shape of the proton resonance absorption e in four substances: (a) water; (b) ice; (c) wdered gypsum, $CaSO_4 \cdot 2H_2O$; (d) a single crystal of psum, suitably oriented with respect to the magnetic d. The contrast between a typical liquid line (a) d the others is actually much greater than the sketch ggests; were the drawing to scale, (a) would be veral times higher and narrower than shown above.

h depend on, and are modified by, the *location* and on of neighboring atoms. The investigation thus s back into the physics of the liquid and solid es.

EPRETATION OF LINE WIDTH AND LINE STRUCTURE

e nuclei are, of course, not *entirely* isolated from netic disturbances of local origin. The most ob- s sources of perturbing magnetic fields are the netic nuclei themselves. A selected proton in a of water is subject not only to any field which ay apply with an electromagnet, but also to the netic fields arising from the magnetic moments of hboring protons in the liquid, including that of other proton in the same water molecule. (The gen nucleus, as Table 1 indicates, is not magnetic.) sum of all such perturbing fields, measured at the tion of a given proton—but, of course, excluding field of that proton—we shall call the "local field," . The local field will vary in magnitude and di- ion, from point to point in the material. It may vary in time. The nature of these variations t now be discussed.

he magnetic field produced by a proton resembles of a short bar magnet. The strength of the field decreases with the inverse cube of the distance. The "lines of force" surrounding such a magnetic dipole are indicated in Fig. 4. The dipole can represent the z-component of the magnetic moment of a proton in the state (−). Let us consider only the z-component of the *field* produced by the dipole, μ, at some nearby point P which might be the location of another proton.

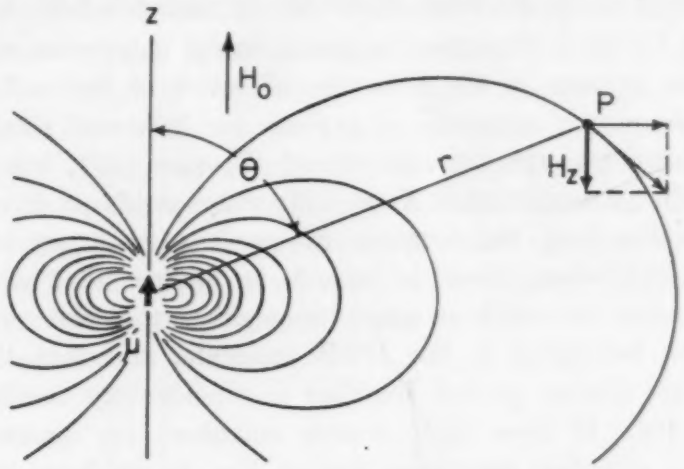

FIG. 4. The magnetic field from a dipole, μ, at a nearby point, P. The magnitude of the component, H_z, is (μ/r^3) $(3\cos^2\theta - 1)$, and the total field at P, in the z-direction, is $H_0 + H_z$. In the cases considered here, $H_z \ll H_0$.

This component of the local field at P is given by

$$(H_{loc})_z = \frac{\mu}{r^3}(3\cos^2\theta - 1),$$

where θ is the angle shown in Fig. 4. Thus the *total* magnetic field, in the z direction, that would be experienced by another proton located at P, is $H_0 + \frac{\mu}{r^3}(3\cos^2\theta - 1)$. If the spin vector of the proton at the origin had been directed downward rather than upward (as we have seen, the states (+) and (−) are almost equally probable) the field at P would have been $H_0 - \frac{\mu}{r^3}(3\cos^2\theta - 1)$.

The "local field" term in each of these expressions amounts to a few gauss, if μ is the proton moment and r is a distance of the order of 10^{-8} cm, whereas the field, H_0, is ordinarily several thousand gauss. The effect of the neighboring protons is thus to alter slightly, either increasing or decreasing, the total magnetic field experienced by a selected proton, and we should expect the resonance condition, for that particular proton, to be modified accordingly to read:

$$\nu = 2\mu(H_0 + H_{loc})/h$$

where H_{loc} represents the instantaneous sum of the fields of all its neighbors. Only the nearest neighbors will contribute significantly to H_{loc}, because of the inverse-cube dependence and the angular dependence of the dipole field.

Although the picture which has been drawn is considerably oversimplified, the gravest omission being the neglect of the effect of the *precession* of the nuclear

dipole, it can serve to explain the main features of the results shown in Fig. 4. Oddly enough, it is easiest to begin with the most complicated of the patterns, Fig. 3 (d), which has been observed and interpreted by Pake (*8*). The four components are observed in a single crystal of gypsum ($CaSO_4 \cdot 2H_2O$) when the crystal axis is oriented in a particular way with respect to the direction of the strong magnetic field, H_0.

The only important magnetic nuclei in gypsum are the protons in the molecules of water of hydration. The crystal structure of gypsum has been well established through the analysis of Wooster (*12*), but it will be recalled that X-ray diffraction yields no direct evidence of the location of protons in a crystal. Nevertheless, there is reason to assume that each proton has one near magnetic neighbor, the other proton belonging to the HOH molecule, and that the next nearest proton neighbor is considerably further away. If these more remote neighbors are ignored, the situation resembles that in Fig. 4; we have isolated interacting *pairs* of magnetic nuclei. Angle θ in Fig. 4 is now the angle between the H–H line in an HOH molecule and the magnetic field H_0. As it turns out, there are only two distinct H–H directions in a gypsum crystal; that is, for a given orientation of the single crystal in the magnet, θ has the same value for half the molecules in the crystal. From the protons in these molecules we should therefore expect a *pair* of resonance lines, symmetrically displaced to either side of the central position by an interval determined by μ, θ, and the interproton distance, r. (The doublet arises from the possibility of the partner being in either the (+) or (–) state.) The remainder of the molecules, to which a different value of θ applies, should give rise to another pair of lines, thus four lines in all. Each of these lines will be smeared out somewhat by the hitherto neglected fields of the more distant neighbors. This is just what is observed. Moreover, as the crystal is rotated in the apparatus, the separation of the components is found to vary precisely in accordance with the factor $3\cos^2\theta - 1$. From these observations, interpreted with the aid of a theory (*8*) more rigorous than we have given here, it is possible to determine not only the directions of the H–H lines with respect to the crystal axes, but also, with a precision of about 1%, the distance between the two protons in the HOH molecule—information which the X-ray analysis does not yield.

If the sample is a powder, rather than a single crystal, all possible values of θ will occur at once. A statistical analysis shows that the resulting superposition of many pairs of lines should yield the double-humped curve which is actually observed in this case (Fig. 3, c). A measurement of the hump separation again permits a determination of the interproton distance, but with less precision than before. The direction of the H–H lines in the crystal cannot be inferred in this case.

When each proton is surrounded by several equidistant near magnetic neighbors, no well-defined structure is observed. One finds instead a single broad line, the width of which, expressed in gauss, is of the order of magnitude, μ/r^3—hence, in general, several gauss. Such a situation is encountered in ice.

We have now to account for the extremely narrow line observed in water and other liquids. The essential difference is that the geometrical configuration of the molecule and its immediate environment can no longer be regarded as static. Instead, we must take into account the thermal motion of the molecule and its neighbors. The time during which the specific orientation of a molecule of the liquid persists can be estimated from the molecular diameter and the viscosity of the liquid. In the case of polar liquids such as water, more direct evidence is provided by the dielectric dispersion; it will be recalled that the existence of molecular orientation plays a central rôle in the Debye theory of polar liquids (*6*). In water at room temperature, this characteristic time is of the order of magnitude of 10^{-11} sec. In a time substantially longer than this, not only will the H–H line of a given molecule have tumbled into a new position, but the configuration and identity of the nearest neighbors will very probably have changed. The local field H_{loc}, at the position of a given proton, is now a quantity which fluctuates in a random manner; the rapidity of fluctuation is very much higher than the resonance frequency for nuclear absorption.

It might be supposed that this rapid Brownian motion would completely obliterate the resonance phenomenon. On the contrary, the nucleus rides out the storm like a well-balanced gyroscope on perfect gimbals. In fact, a careful statistical treatment shows that the very rapidity of the fluctuations reduces the perturbing effect, the appropriate *average* value of H_{loc} being very much smaller than its instantaneous magnitude. The width thus predicted for the proton resonance in water is even smaller than that observed. The observed line width is caused by lack of perfect homogeneity in the field of the electromagnet.

If the viscosity of the liquid is increased, as by lowering its temperature, the local Brownian motion becomes less rapid, the perturbations due to the local field become *more* effective, and the absorption line broadens. Proceeding to the limit in this direction, the local motion is finally frozen out, and the line attains a width characteristic of a crystal. This whole range of behavior has been observed in glycerol, with results in quantitative agreement with the theory. Even in solids a certain amount of local motion persists well be-

the freezing point, as other lines of evidence strongly indicate (*9*), and the width of the proton line increases somewhat, with decreasing temperature, in the range $-5°$ C to $-40°$ C.

The nuclear resonance line width is thus a sensitive indicator, in some circumstances, of internal motion on a molecular scale. By this means, Bitter and Alpert and others at the Massachusetts Institute of Technology have recently investigated the so-called λ-point transitions in certain crystals. These transitions are marked by anomalies in the specific heat and have been attributed by various investigators to the more or less abrupt "freezing-in" of internal degrees of freedom associated with the rotation or oscillation of molecular groups. Solid methane, for example, displays a λ-point in the neighborhood of 20° K. Alpert (*1*) found that the width of the proton line in methane decreased markedly as the temperature of the solid was elevated through the λ-point and interpreted this as evidence for the activation of a *rotational* rather than a *vibrational* degree of freedom. In deuterated methane, which displays two λ-points, he found a similar behavior at the upper λ-point. Solid HCl and natural rubber were also investigated.

Nuclear Relaxation

We return now to the question raised earlier: How are the nuclear spins brought into thermal equilibrium with the rest of the sample? It is seldom necessary to ask this question about an atomic or molecular system. A few interatomic collisions, occurring within 10^{-9} sec or so, suffice to bring about equilibrium. So thoroughly insulated is the nucleus, however, that in many substances *several seconds* are required for the populations of the levels (+) and (−) in Fig. 1 to adjust themselves into conformity with the Boltzmann factor. This time is called the thermal relaxation time of the nuclear spins. It is perhaps surprising to find a time so long associated with any atomic process; as a matter of fact, previous theoretical studies of this question had predicted even longer relaxation times than were observed. Two tasks were thus presented: (1) to measure the nuclear relaxation time in various substances under many conditions; (2) to devise an adequate theoretical explanation of the phenomenon. Although the problem is by no means completely solved, it is now possible to account rather satisfactorily for the relaxation effects observed in liquids and in a restricted class of solids (*5*). We can only indicate here the connection between nuclear relaxation and those features of the liquid or solid structure which have already been encountered in our discussion of line width.

Exchange of energy—that is, "thermal contact"—between the nuclear spins and their surroundings requires the existence at the nucleus of oscillating magnetic fields that (a) satisfy the resonance condition and are hence capable of inducing (+) → (−) and (−) → (+) transitions, and (b) originate in the thermal motion of the surroundings. Just such a mechanism is provided by the local Brownian motion which, as we have seen, causes a rapid and random variation of the local field produced by neighboring magnetic nuclei. One has to turn to the theory of random processes to compute the effective intensity, in the "spectrum" of the fluctuating local field, of the particular frequency required. One finds that the intensity is sufficient to explain the effects observed, and that a theory can be constructed which successfully accounts for the observed variation of nuclear relaxation time with the viscosity of the liquid.

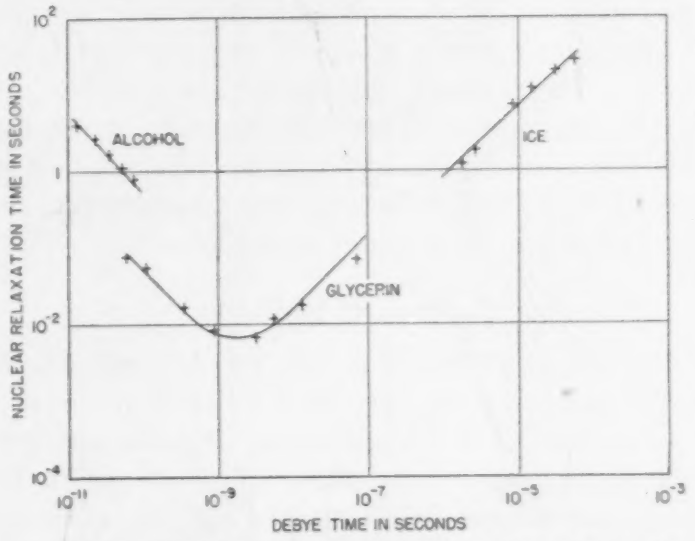

Fig. 5. The thermal relaxation time for protons in ethyl alcohol, glycerin, and ice, measured at 29 Mc/sec, plotted against the Debye relaxation time, obtained from dielectric dispersion data. Note the logarithmic scales. The slope of the solid lines for alcohol and ice and the shape of the solid curve for glycerin have been drawn in accordance with the theory.

Again, the important parameter is the characteristic time for reorientation of a molecule and redeployment of its neighbors, which, as noted earlier, is closely related to the characteristic time in the Debye theory of dielectric dispersion. In Fig. 5 the observed nuclear relaxation times, in ethyl alcohol, glycerin, and ice, are plotted against the "Debye characteristic time" obtained from published data on dielectric dispersion. Each of the points belonging to one of the curves was obtained at a different temperature. The curves are drawn in accordance with theory. The agreement is as good as one could expect, and it can be said with some confidence that the main features of the process of nuclear relaxation in these substances are understood.

So far as the structure of the substance is concerned, one learns from these curves only what could be learned from measurement of the resonance line width or, forgetting about the nucleus, from measure-

ments of dielectric dispersion. However, the relaxation time can be measured even when the true line width is too small to be resolved, and the method applies equally well to nonpolar liquids which would not show dielectric dispersion.

One of the most interesting problems encountered in the study of nuclear relaxation is still unsolved. In many crystals the nuclear relaxation time appears to be much too short to be explained by any existing theory. The most striking evidence of the inadequacy of existing theories comes from the work of B. V. Rollin and collaborators at Oxford, who have investigated nuclear relaxation at very low temperatures (*11*). They report a relaxation time of the order of 5 sec for Li^7 nuclei in lithium fluoride, at a temperature of 2° K. The mechanism which brings about so rapid an exchange of energy between the nuclear spins and their environment, at this low temperature, is unknown. The thermal vibration of the nuclei in the crystal lattice, *even at room temperature,* is not violent enough to explain a relaxation time as short as this. It is difficult to imagine any other internal degree of freedom in a crystal of this type.

Concluding Remarks

Other lines of investigation, which could not be traced in detail here, have been followed far enough to suggest interesting applications of nuclear magnetism to problems of structure. The interaction between nuclear magnetic moments and the electronic magnetic moments of paramagnetic ions in solution, studied in a preliminary way by Bloembergen (*5*), depends upon the distance of closest approach of a magnetic ion to the nucleus in question, and hence upon the size and permanence of any complex surrounding the nucleus. R. V. Pound has very recently found evidence of interaction between the interatomic *electric* fields in a crystal and the electric quadrupole moment of a nucleus—a property of some nuclei which has been ignored in this article. It is too early to foresee the significance of this development.

To survey a field at such an early stage in its development is doubtless a rash venture. In the process of simplifying and condensing the statement of the problems, one runs the risk of creating an impression of tidiness which the actual state of affairs does not justify. More serious, perhaps, is the danger of exaggerating the importance of the information which the new techniques make available and the ease with which it can be obtained. On this last point, it should be said that the quantitative measurement of relaxation time and line shape is not easy. Nuclear resonance absorption is, after all, a feeble effect. The peak intensity of absorption in ice is such that a radio wave of the resonant frequency would be attenuated to half its amplitude only after traversing some hundred kilometers of solid ice. The data recorded in Fig. 5 were obtained from a sample weighing less than 1 gm. Despite this difficulty, I think we can look forward to the profitable development and extension of the field which these early experiments have opened.

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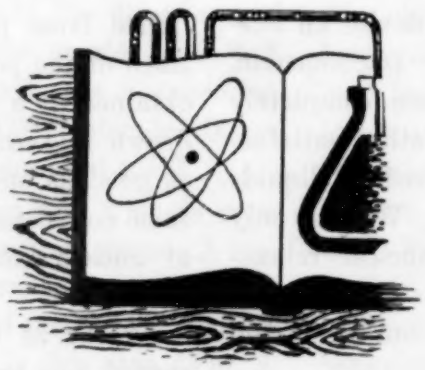

NEWS and Notes

At a meeting of the Executive Committee of the AAAS on Saturday, April 24, the following resolution with respect to military training was unanimously passed:

In order to safeguard the development and maintenance of the scientific manpower essential for our national welfare, the Executive Committee of the American Association for the Advancement of Science deems it essential that laws covering the manpower needs of our military forces do not interrupt the continued training of qualified students in the natural sciences on the undergraduate and the graduate level.

About People

Fritz Zwicky, California Institute of Technology astrophysicist, has been selected to give this year's Halley Lecture at Oxford University on May 12. His subject will be "Morphological Astronomy." This lectureship, founded in 1910 in memory of Edmund Halley, for whom Halley's Comet was named, has been given each year by outstanding astronomers and astrophysicists throughout the world. Prior to the lecture Dr. Zwicky will visit the Paris Observatory and will spend a short time in Switzerland. At Oxford he will also deliver an engineering lecture on "The Morphology of Jet Propulsion," a field in which he has also done extensive work.

Christopher E. Barthel, Jr., has been appointed chairman of physics research at Armour Research Foundation of Illinois Institute of Technology, to succeed **Haldon A. Leedy,** who recently became director of the Foundation. Dr. Barthel has been supervising the activities of light and optics, X-ray diffraction, and spectroscopy sections of physics research since joining the staff of the Foundation in November 1947.

Roland G. D. Richardson, dean of the Brown University Graduate School, will retire at the end of the present academic year after 41 years of service to Brown. Dr. Richardson, who was chairman of the Department of Mathematics from 1915 to 1942, has for many years been actively engaged in promoting in this country an interest in applied mathematics. He was secretary of the American Mathematical Society for 20 years.

William A. Starin, chairman of the Ohio State University Department of Bacteriology, will retire from active service at the end of the current academic year after 38 years of teaching at the University. Friends and former students are holding a dinner in his honor on May 8 at the Neil House in Columbus. In addition, the William A. Starin Lectureship has been established through the Ohio State University Development Fund and will be administered by the Department of Bacteriology in consultation with the Dean of the Graduate School. All of Dr. Starin's friends and former students who can be contacted are being asked to send to Margaret D. Heise, of the Department of Bacteriology, such contributions as they desire toward the fund, which will become part of the University's permanent endowment and provide an annual speaker.

Grants and Awards

Under a grant of $4,600 from the Viking Fund Gabriel Lasker and F. G. Evans, assistant professors of anatomy at Wayne University, will spend 5½ months in Mexico during the coming academic year to obtain data for a study which they will conduct on the effects of migration on hereditary physical traits in Mexicans. Wayne University affords a fortunate location for such a study because of the large number of Mexican immigrant laborers in Detroit and the Thumo district of Michigan.

The Viking Fund Medal for distinguished contributions to physical anthropology was presented this year to Earnest A. Hooton, professor of anthropology at Harvard University, at the annual dinner of the American Association of Physical Anthropologists, held in Frazier Hall, Howard University, Washington, D. C., on April 3. The award was made during the Association's 17th annual meetings. On the cover of this issue Dr. Hooton is shown receiving the medal from Ralph Linton (left), professor of anthropology at Yale University, while W. M. Krogman (center), professor of physical anthropology in the Graduate School of Medicine, University of Pennsylvania, and president of the Association, looks on.

At the 50th Anniversary Dinner of the Geographic Society of Chicago, February 21, President Henry M. Leppard presented several awards. The Helen Culver Gold Medal went to Wallace W. Atwood, Sr., "for distinguished research in physical geography and as a founder of the Society," to Charles C. Colby "for distinguished leadership on the frontiers of geographic thought," to Vernor C. Finch "for distinguished contributions in economic geography," and to Derwent S. Whittlesey "for distinguished achievement in political geography." Merit Awards for recent publications in geography were presented to Glenn T. Trewartha for *Japan: a physical, cultural and regional geography,* to Stephen B. Jones for *Boundary-making: a handbook for statesmen, treaty editors, and boundary commissioners,* and to Malcolm J. Proudfoot for *Measurement of geographic area.* Citations for distinguished service as geographic editors were awarded to W. E. Ekblaw, editor of *Economic Geography,* George J. Miller, editor of the *Journal of Geography,* and Gladys M. Wrigley, editor of the *Geographical Review.*

At the annual dinner of the American Institute of Nutrition, held in the Jefferson Hotel, Atlantic City, on March 16, two awards were made. The Mead Johnson and Company Award for work on the Vitamin B Complex went to Fritz Lipmann, head of the

Biochemical Research Laboratory, Massachusetts General Hospital, "for his work on the identification of pantothenic acid as a component of coenzyme A and to the recognition of its biochemical role in enzymatic acetylation and in the biological oxidation of acetic acid." Dr. Lipmann recently received the Carl Neuberg Medal of the American Society of European Chemists and Pharmacists for this same research contribution. Charles A. Cary, chief of the Division of Nutrition and Physiology, Bureau of Dairy Industry, USDA, received the Borden Award "for his research concerning the influence of diet on the composition of blood and milk constituents; occurrence and losses of carotene in roughage; vitamin A potency of milk and butter and the relation of same to the quality of roughage; unidentified nutrients necessary for normal growth which are found in milk and milk products and in certain other foods and feeds."

Meetings

Activities of the International Cancer Research Commission were discussed during conferences held in Mexico City March 24–31 between the Minister of Health, Rafael Pascicio Gamboa, the Sub-Secretario Salubridad Publica, Ignacio Morones Prieto, Ignacio G. Millan, chairman of the Commission, and E. V. Cowdry, member for the United States on the Commission. Agreement was reached regarding quarters and operation of the Commission during the three years that its headquarters will be in Mexico and Dr. Millan will serve as chairman. After this period headquarters will be established in some other country which will thus follow the example of Mexico in international leadership in cancer research.

Plans were also made for the first annual meeting of the Commission in Paris on October 17–21 of this year. It is expected that each of the 40 member nations will send a representative to this meeting, and it is hoped that before then the 20 other nations which have officially expressed interest in international cooperation in cancer research will likewise arrange representation. Among the problems to be discussed are the construction of a standard form for taking the clinical histories of cancer patients, the achievement of some uniformity in tumor registries, and the formulation of a cancer nomenclature acceptable to all nations.

Progress along these lines will facilitate cooperation between nations. In the spread of accurate information bearing on cancer research the members of the Commission, who are strategically located throughout the world, already have been helpful. Each nation, however large or small, is represented on the Commission by a single individual whose term of service is limited to three years. Anyone seeking data about cancer in any particular country or where in it equipment can best be obtained should write to Dr. Ignacio G. Millan, 69 Avenida Vera Cruz, Mexico City, who will refer the inquiry to the proper person. It is expected that this information service will expand.

The Executive Committee of the Commission consists of Ignacio Millan (chairman), Avenida Vera Cruz 69, Mexico, D. F. (Mexico), Alternate, Felix E. Leborgne (Uruguay); E. V. Cowdry (U. S.), Alternate, W. U. Gardner (U. S.); A. Haddow (England), Alternate, J. Engelbreth-Holm (Denmark); V. R. Khanolkar (India), Alternate, Tu-Shan-Jung (China); J. Maisin (Belgium), Alternate, A. Lacassagne (France).

This International Cancer Research Commission is not to be confused with the Fourth International Cancer Research Congress held in St. Louis last September and attended by 820 cancer specialists. At the Congress the smaller Commission, at present consisting of 40 persons representing 40 nations, was established. The Fourth Congress will be followed in 1950 by a Fifth Congress. In the interim the Congress is inactive except for the publication and circulation of its transactions under the direction of J. Maisin, of the University of Louvain, Belgium, to whom any inquiries should be addressed. The Commission, on the other hand, functions continuously and will have yearly meetings, never twice consecutively in the same country. It enjoys the status of an almost completely autonomous committee of the Union Internationale Contre le Cancer. A report on the Commission has been forwarded by the U. S. Department of State to all nations invited through the Department to participate in the Congress. The journal *Cancer Research* will soon publish a description of the Commission. (E. V. COWDRY.)

On April 17 Connecticut College was host to the 13th annual Connecticut Valley Student Scientific Conference, in which 350 representatives of 11 New England colleges participated. Keynote speaker was Ernest C. Pollard, of the Department of Physics, Yale University, whose subject was "The Widening Field of Physical Research." Each of the sections (Botany and Bacteriology, Chemistry, Home Economics, Mathematics, Physics and Astronomy, Psychology, Zoology and Physiology) consisted of demonstrations, exhibits, and scientific papers.

These conferences, planned by students for students and patterned after national scientific meetings, were held annually from 1931 to 1942, at which time they were suspended because of the war. This, the first such meeting since the war, was participated in by American International, Dartmouth, Mount Holyoke, Saint Joseph, Smith, Springfield, and Connecticut Colleges, Wesleyan University, the Universities of Connecticut and Massachusetts, and the U. S. Coast Guard Academy. Eleanor Penfield, Connecticut College senior, was chairman.

NRC News

The study of the Pleistocene epoch —the last million years or more of geologic time—involves a unique situation. In the broad sense this field of study is geologic, for it embraces the entire record of an established unit of Earth history. But when viewed more closely, this field, while still the province of the geologist, has a number of highly important facets that are also the concern of other sciences. The anthropologist and the archeologist are concerned with early man and his industry, a vast area that lies largely within the Pleistocene

amework. The botanist and the zoogist are concerned with the succession of geographic assemblages of ants and animals that have preceded present ones; this inquiry merges with the work of the paleontologist. The climatologist inquires into the character and succession of climates in various parts of the world during the Pleistocene as well as in earlier times. The pedologist is interested in the changes that have affected the soil-making processes during the Pleistocene and in their climatic implications. The glaciologist is interested in the genesis and properties of the various kinds of ice that played an important part in Pleistocene world history. Biogeographers, too, have a significant interest in various aspects of these problems.

Within the discipline of geology itself, Pleistocene research is compartmented. The glacial geologist, the stratigrapher, the paleontologist, the student of sediments, the geomorphologist, the structural geologist, and the sea-floor geologist (a comparatively new species of research worker) each has his own interest and his own approach to Pleistocene problems.

All these people are working toward the same end, toward a single final synthesis; yet the obstacles in the way of their free communication with each other while en route to their goal are numerous. The departmentalization of universities, museums, and government research institutions operates to keep many of these workers apart. Also, it inhibits the distribution of research funds outside the limits of conventional channels. The means of publication, likewise, are departmentalized, so that it is impossible for a worker interested in the whole field of the Pleistocene to cover the current literature in Pleistocene research or even to be aware of the existence of much of it.

From these facts it is apparent that the student of almost any phase of Pleistocene research is working to some extent in the dark. To make this research more meaningful and more efficient, coordination is needed—some method of lateral contact to cut across the organizational bulkheads that interfere with progress.

Realizing this need, the Division of Geology and Geography set up in June 1947 a Committee on Interrelations of Pleistocene Research. Including representatives of most of the fields of interest in the Pleistocene, the Committee is charged with attempting to furnish the much-needed lateral coordination. The members are: Edward S. Deevey, Jr., Department of Biology, Yale University (biogeography); Loren C. Eiseley, Department of Anthropology, University of Pennsylvania (anthropology and new-world archeology); Richard Foster Flint, Department of Geology, Yale University, chairman of the Committee; Claude W. Hibbard, Museum of Paleontology, University of Michigan (vertebrate paleontology); Chauncey D. Holmes, Department of Geology, University of Missouri (glacial erosion and sedimentation); Helmut E. Landsberg, Committee on Geophysical Sciences, Research and Development Board, Washington, D. C. (meteorology and climatology); Hallam L. Movius, Jr., Peabody Museum of Archaeology and Ethnology, Harvard University (old-world archeology); Fred B. Phleger, Jr., Department of Geology, Amherst College (oceanography and sea-floor geology); Louis L. Ray, U. S. Geological Survey, Washington, D. C. (glacial stratigraphy; alpine glacial geology); H. T. U. Smith, Department of Geology, University of Kansas (Eolian features; frozen ground; stream terraces); and James Thorp, Division of Soil Survey, U. S. Department of Agriculture, Lincoln, Nebraska (soil science). It is hoped that representatives of other fields of interest will be added later.

The whole committee met in New Haven on April 5–6 to explore its problems and to define its task. As far as the writer knows, this is the first time a group of active representatives of these fields has met to discuss the general problems of Pleistocene research. The results were stimulating to a high degree. The concrete aspects of the Committee's program will be announced in due course.

The Committee invites constructive suggestions from all interested scientists. These should be sent to the appropriate individual members, if they are concerned with special fields, or to the chairman, if they have general application. (RICHARD FOSTER FLINT, *Chairman.*)

Deaths

James K. Whittemore, 72, associate professor emeritus of mathematics at Yale University, died March 22.

Lewis G. Westgate, 79, emeritus professor of geology at Ohio Wesleyan University, died March 30 at his home in Delaware, Ohio. He had been a professor at the University from 1900 until his retirement in 1939 and resumed his duties from 1942 to 1944.

Clara Latimer Bacon, 81, emeritus professor of mathematics at Goucher College, died April 14 in Baltimore, Maryland. Dr. Bacon retired from her teaching duties in 1934.

Alfred C. Lane, 85, formerly Pearson professor of geology and mineralogy at Tufts College, died April 15 in Cambridge, Massachusetts. At one time Dr. Lane had been head of the National Research Council's committee on estimation of geologic time by atomic disintegration and was president of the Geological Society of America in 1931.

The Philosophy of Science Association has been reorganized with Philipp Frank, of Harvard University, as president and C. West Churchman, of Wayne University, Detroit, as secretary-treasurer. Members of the Governing Committee are Gustav Bergmann, State University of Iowa; Thomas A. Cowan, Wayne University; Clyde Kluckhohn, Harvard University; Sebastian Littauer, Columbia University; and F. S. C. Northrop, Yale University.

Applications for membership ($5.00 per year) may be sent to the secretary-treasurer. The Association encourages the establishment of local groups in the philosophy of science.

Prof. Churchman is acting editor of *Philosophy of Science*, the Association's official journal, and manuscripts should be sent to him.

The Institute of International Education has recently outlined the latest developments with respect to the Fulbright Act (Public Law No.

584) (see *Science*, May 9, 1947, pp. 483–485; July 25, 1947, p. 78). We are now informed that agreements have been signed with three countries —China, Burma, and the Philippines— and that the Board of Foreign Scholarships has approved programs of educational exchanges with the first two of these. Negotiations are still in progress with Australia, Austria, Belgium, Egypt, France, Greece, Iran, Italy, the Netherlands, the Netherlands East Indies, New Zealand, Norway, Siam, Turkey, and the United Kingdom.

Since the money available from the sale of surplus property abroad is in foreign currencies and not convertible to American dollars, individual arrangements must be made for each American participant in the program for such dollar balances as he will require to meet his family needs and other obligations in the United States during the period of his absence abroad.

The types of activities envisaged under the Act include: (1) aid in international reconstruction by assisting foreign countries to secure the services of American specialists in various fields to assist the peoples of these countries in understanding the American people, their achievements, and their ideals; (2) provision for Americans to study, teach, and do research abroad, thus adding to our knowledge of foreign areas, peoples, and cultures; (3) opportunities for a limited number of foreign students to study in American institutions abroad and to assist foreign students and teachers to engage in educational activities in the United States by paying for their transportation in cases where foreign currencies can be used.

The program as approved for China is as follows: 20 U. S. professors to go to Chinese universities; 10 U. S. advanced research scholars (post-Ph.D.) to carry on work in China; 20 U. S. graduate students to study in China; 30 Chinese students and professors to receive travel grants to the U. S.; and 100 Chinese students to study in American colleges and universities in China.

No transportation funds to or from China are available at the present time, nor do Fulbright grants for study abroad, made for a full academic year, cover members of the grantee's family. The deadline for return of applications for study in China is June 1.

The program for Burma includes: 8 U. S. professors and specialists to Burma; 5 U. S. research scholars to Burma; 5 U. S. graduate students to Burma; 2 U. S. secondary school teachers to the Village Teachers Training School and the State Post-Primary School; 5 Burmese students to the Medical Center for Frontier Areas in Burma; and a limited number of Burmese students' travel grants to the U. S.

Travel funds to and from Burma are available.

The Philippine program has not been announced.

Inquiries and requests for applications should be addressed to the administering agencies. These are: Fulbright Division, Institute of International Education, 2 West 45th Street, New York City 19 (for predoctoral graduate students); Conference Board of Associated Research Councils, 2101 Constitution Avenue, Washington 25, D. C. (for professors, specialists, and post-Ph.D. research scholars); U. S. Office of Education, Washington 25, D. C. (for American teachers in *national* schools abroad); Dr. Roy T. Davis, Director, Schools Service, American Council on Education, 744 Jackson Place, Washington 6, D. C. (for American teachers in *American* schools abroad). U. S. and foreign citizens *abroad* should make application to the U. S. Educational Foundation at the U. S. Embassy or Legation in the country in which they are resident. Applications should be made only for countries with which agreements have been concluded.

The Wasmann Collector, formerly the journal of the Wasmann Biological Society, is now being published jointly by Loyola University of Los Angeles and the University of San Francisco. Membership in the Society is no longer required of contributors. Manuscripts and requests for sample copies of the journal (now in its 7th volume) should be addressed to Edward L. Kessel, the managing editor, Department of Biology, University of San Francisco, San Francisco 17, California. The board of associ editors consists of Carl G. Kab and Roland A. Reed, S.J., repres ing Loyola University; Frank P. ice, Harold A. Harper, and Robert Orr, from the University of San Fr cisco; and John T. Howell, guest ed from the California Academy Sciences.

Corrections: In the announcem of recent elections to the Board Trustees of *Biological Abstracts* (*ence*, March 26, p. 316) Stuart M of the University of Pennsylva should have been listed as vice-pr dent rather than Charles N. Frey.

In describing the cover photo of March 26 issue we neglected to st that the underwater photograph of sea spider was taken from the *Atla* of the Woods Hole Oceanographic stitution.

Make Plans for—

4th International Congresses Tropical Medicine and Malaria, 10–18, Department of State A torium, Washington, D. C.

Indiana Academy of Science, nual spring meeting, May 1 Shades State Park, Waveland, Indi

American Association on Me Deficiency, annual meeting, May 22, Copley-Plaza Hotel, Boston, M sachusetts.

Symposium on Spectrosc Equipment, under joint auspices the Society for Applied Spectros and the Polytechnic Institute Brooklyn, May 22, Brooklyn, York.

American Iron & Steel Insti May 26–27, Waldorf-Astoria H New York City.

Medical Library Association, nual meeting, May 28–30, Hotel W wick, Philadelphia, Pennsylvania.

National Gastroenterological sociation, 13th annual conven June 7–10, Hotel Pennsylvania, York City.

American Dairy Science Asso tion, 43rd annual convention, June 16, University of Georgia, Athen

American Mathematical Soci June 19, University of British Col bia, Vancouver.

Comments and Communications

Taxonomic Characteristics for *Amoebae*

In a recent communication by King and Jahn (*Science*, March 19, pp. 293–294) it has been suggested that the names *Amoeba proteus*, *Chaos carolinensis*, and *Pelomyxa palustris* be used in referring to the well-known species *Amoeba proteus* Leidy, *Pelomyxa carolinensis* Wilson, and *Pelomyxa palustris* Greeff, respectively. The argument is based on the contention that "the type of locomotion of an ameba is one of its principal taxonomic characters."

It is maintained that "*P. palustris* does not ordinarily form pseudopodia, and certainly it does not locomote by means of pseudopodia." Furthermore, it is held that locomotion in *Amoeba proteus* and in *Pelomyxa carolinensis* is the same, for which reason Schaeffer put them into the same genus, *Chaos*.

Facts reported in the literature do not support the contentions of King and Jahn, however. It is known from the work of Mast that "the process of locomotion in *Pelomyxa palustris* is essentially the same as in *Amoeba proteus*" (*Physical. Zool.*, 1934, 7, 470–478). Moreover, Wilber has shown that there are consistent differences in the details of locomotion in *Amoeba proteus* and *Pelomyxa carolinensis* (*Trans. Amer. mic. Soc.*, 1946, 65, 318–322). If the published facts contradict the premises of these authors, it is obvious that the method of locomotion is not a "valid generic character."

King and Jahn refer to a quotation from a paper by Wilber (*Trans. Amer. mic. Soc.*, 1947, 66, 99–101) in which it is stated that general differences of form are unsafe taxonomic characters for amebas. They say that in view of Schaeffer's 1926 monograph the stated position is invalid. Moreover, they seem to imply that because one paragraph is questioned by them, the conclusions in the paper (to the effect that *Amoeba proteus* and *Pelomyxa carolinensis* are valid species properly named) are unwarranted. They fail to point out that in the same paper reference is made to the writings of Greeff, Wilson, Lankester, Kudo, and others, all of whom support the contention that the "nuclear condition is of first importance in determining whether a rhizopod is an *Amoeba* or a *Pelomyxa*."

General shape of amebas and superficial characteristics of locomotion are dangerous to use as taxonomic norms because environmental factors of various sorts exert profound changes in the form of *Amoeba* (see Mast. *J. exp. Zool.*, 1928, 51, 97–120). Such factors do not, however, change the nuclear condition.

Kudo (*J. Morphol.*, 1946, 78, 317–352) has discussed the question of nomenclature for the genus *Pelomyxa* and comes to the conclusion that "it seems reasonable to consider that *P. palustris* and *P. carolinensis* are two valid and distinct species."

In view of the fact that the evidence in the literature does not support the view of King and Jahn, it seems that their breakdown of these controversial rhizopods into three genera is unwarranted. The weight of present evidence indicates that the following are valid species: *Amoeba proteus*, *Pelomyxa carolinensis*, *Pelomyxa palustris*.

CHARLES G. WILBER

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The Native Proteins as Polycondensations of Amino Acids

The native proteins are polycondensations of α-amino acids, NH_2—HC_aR—COOH, about 21 different species and 2 cyclic amino acids being obtained to date. The proteins are of unknown structure, and the question then arises as to the light which organic polycondensations of known structure can throw upon this problem. So far there has been no indication of a stepwise polycondensation resulting in the synthesis of protein. However, just as the structure of the silicates can be resolved without reference to geochemistry, so the structure of proteins can be studied without reference to the anabolic path. The known atomic patterns of minerals (W. L. Bragg. *Atomic patterns of minerals.* Ithaca, N. Y.: Cornell Univ. Press, 1937) indicate how these structures can be formalistically analyzed into certain "monomer" units, in a definite spatial pattern. The study of proteins has a similar objective—the discovery of the spatial patterns in which the amino acid residues are interlocked.

There are a few similarities between organic high polymers in general and proteins in particular. Both comprise large molecules in which many atoms are interlocked by primary valences; in both, secondary valences can affect the formation of particles whose size and shape may vary widely with variations in the experimental conditions. The dissimilarities, however, prove to be more numerous and more significant. (1) High-molecular-weight materials, in general, are not uniform and do not consist of molecules or particles which are chemically identical. The word *macromolecular* focuses attention on this fact. The word *megamolecular* was correspondingly introduced to focus attention on the diametrically different situation in the proteins. (2) Proteins, in general, crystallize—and indeed maintain their existence—only with the aid of foreign molecules or ions, notably water. Furthermore, one and the same protein can crystallize with different water complements (D. Crowfoot. *Chem. Rev.*, 1941, 28, 215). (3) The single category of substance, protein, has already yielded crystals belonging to all the crystal systems. (4) The incidence of high, even cubic, symmetry, among the crystalline proteins, distinguishes them from all other organic materials. (5) Twins and intergrowths are frequently observed. (6) Macromolecular substances do not crystallize with anything approaching the degree of perfection of small molecules. By contrast, X-ray diffraction patterns, indicating a very high degree of regularity, have been obtained from certain proteins in their mother liquor (Crowfoot, *op. cit.*). (7) All the amino acids in proteins have

the same (levo) configuration. By contrast, macromolecular polypeptides recently obtained can incorporate both dextro and levo residues. (8) Proteins, with their tendency to 'denature,' are intrinsically unstable, a characteristic setting them apart from most—possibly all—other substances.

These many differences carry a number of implications. (1) There is a deep-seated antithesis between the structure of organic macromolecules and of protein molecules. A macromolecule, whether it is a chain (with or without branches or cross bonds) or whether it is a 2- or 3-dimensional network, is 'open': it comprises any one of a range of different numbers of monomers, the range being dependent on the method of preparation. Evidently a protein, by contrast, comprises a coherent, integrated spatial pattern of its residues. The growing indications that many proteins are particles and not molecules emphasizes the possibility that proteins may contain relatively few residues per molecule. Thus, with the emergence of insulin as a trimer (J. L. Oncley. *Science*, 1947, **106**, 509) comprising 3 subparticles (which may or may not be molecules), the molecules apparently have a maximum molecular weight of ~ 12,000. Such relatively small molecules would resolve the apparent conflict between the hypothesis of characteristic skeletons for all proteins and the wide variety of 'molecular' weights and shapes. Actually, it is already known in numerous cases that such weights and shapes refer to particles, not to molecules. (2) The characteristics of crystalline proteins mentioned above in (3) and (4) have already been encountered in crystallography—in the silicates and alumino-silicates (Bragg, *op. cit.*). There they are known to be a direct indication of the presence of a major theme, comprising a cubic motif or a motif on a cubic lattice or lattices, accompanied by a minor theme which may or may not be cubic. This permits the interpretation of these protein characteristics on similar lines (D. Wrinch. *Amer. Mineral.*, 1947, **32**, 695; 1948, in press). In this event, the major theme would be the interlocked (N—C_α—C) skeletons of the protein molecules; the minor theme, the R-substituents and the foreign molecules or ions. This viewpoint gains support from the fact that many of the hemoglobin twins can then be interpreted, as in the case of inorganic twins (e.g. staurolite, tetrahedrite), as due to the emergence of the major theme. (3) To interlock into skeletons which are cubic or lie on a cubic lattice or lattices, the anorthic (N—C_α—C) units require, in some or all cases, a functionality higher than two. It is suggested that this higher functionality, which distinguishes a protein from a Fischer polypeptide or a cyclic polypeptide (D. Wrinch. *Proc. roy. Soc.*, 1937, **A160**, 59; *Phil. Mag.*, 1938, **25**, 705; 1947, **38**, 373; *J. Amer. chem. Soc.*, 1941, **63**, 330), is effected by means of a labile bond (explaining the intrinsic instability of protein molecules), and that the opening of labile bonds, *i.e.* disjoining of the molecular skeletons, is the real meaning of the so called 'denaturation' of proteins, a phenomenon entirely distinct from dissociation of a particle into subparticles or molecules. (4) To form crystals of so high a degree of regularity, protein molecules must be capable of multipoint associations. Precisely this problem is successfully solved by the large phosphotungstic acid anion by a cubic structure whose enveloping polyhedron apposes its faces to form symmetric intermolecular associations and symmetric associations with symmetric water clusters. The points of similarity between the proteins and the 5- and 29-hydrates of phosphotungstic acid (Wrinch, *op. cit.*) suggest a similar picture for proteins. The occurrence, in 2s and 3s and 6s and 12s of certain amino acids would be expected in protein molecules, though not necessarily in protein particles, if the intermolecular protein associations are also to have symmetry elements. (5) The uniform (levo) character of the amino acids in proteins seems to be the clearest indication of a "surface" structure for protein skeletons, the uniform configuration then permitting the emergence of all Rs. It has recently been shown that this same conclusion, a structure one residue thick, follows from the study of the nature of protein replication (Wrinch, *op. cit.*). It is also supported by the fact that many proteins, diverse in nature, form monolayers on the surface of water with thicknesses of 7–11 A. (6) The nature of the labile bond in protein skeletons remains to be established. A lactim-lactam transformation has been suggested (Wrinch, *op. cit.*). Such a viewpoint affords simple interpretations of recent studies of denaturation and of degradation products of proteins. Taken with (4), the hypothesis that protein structure is, for the most part, an exercise in the interlocking of oligo-peptides presents itself. In the original formulation (Wrinch, *op. cit.*), these comprised cyclic hexapeptides and tetrapeptides. It may now be pointed out that the coherence of the smallest such structure can be maintained with 4 hexapeptides plus 6 tetrapeptides or 8 hexapeptides, yielding a skeleton residue number of 48 and molecular weight slightly below 6,000. These two 48-residue structures suggest that complete cyclic hexapeptides or tetrapeptides or smaller peptides can be incorporated into, or deleted from, protein molecules without disjoining the skeleton, a picture which may be studied in connection with Schoenheimer's original results and with the relations between certain proteins and their precursors. Each 48-residue structure has 24 residues still in the bifunctional form. Here, then, are sites for the insertion of residues or peptides by one terminal only, leaving a free backbone —NH_2, such as have been found for some proteins and/or a free backbone—COOH. In this event some of the residues covered by the chemical analysis of a protein may be functioning as substituents on, rather than as parts of, the molecular skeleton, with the residue number and the skeletal residue number no longer identical. Significance in terms of symmetry elements is only to be expected for the latter. 'Raw edges,' when present, may also be sites for synthesis of nonprotein structures, and there are indications that the close biological relationship between the proteins and the alkaloids and the nucleic acids has its locus at such positions on the molecular skeletons of proteins.

DOROTHY WRINCH

Smith College

TECHNICAL PAPERS

otal White Cell Counts of Peripheral od Heart Blood of the Rat

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Little attention has been given to the possible differ- e in white cell distribution in the circulatory system. w and Heston (*6*) found a marked difference in the al white cell count of heart and peripheral blood in ino mice. Since these workers employed nembutal sthesia before making the cardiac puncture (*7*) and ce nembutal has been shown to produce hemodilution experimental animals (*1–3, 5*), there remained the ques- of whether the low white count of blood taken from heart was due to the anesthesia or was a normal con- ion in the unanesthetized animal.

Blood samples were taken from the periphery and heart 10 adult male albino rats. The peripheral blood sample obtained by clipping the tip of the tail and using the -flowing blood. The heart blood was taken by cardiac cture immediately after stunning the rat with a blow the head. Total white cell counts were made on the od sample. In order to ascertain any possible alter- n in blood concentration as a result of the head blow, rminations were also made on the red cell numbers

TABLE 1

(Average of 10 animals)

	Peripheral	Heart
ite cell umbers/mm³	23,810	6,425
d cell umbers/mm³	8,967,000	8,790,000
cific gravity f blood	1.0529	1.0526

the specific gravity of the blood. The blood cell nts were made by use of standard dilution pipettes, uting fluids, and hemocytometers. The specific gravity the blood was determined by the copper sulfate method Phillips, *et al.* (*4*). The results are summarized in ble 1.

It is clear from the data in Table 1 that, while the red numbers and density of the blood taken from the tail d heart are of the same value, there is a marked differ- e in the white cell count. This shows that the blood m the two sources is of uniform concentration and that low white count of the heart blood is not due to hemo- tion. While it may be true that the extremely low ocyte count obtained by Law and Heston (*6*) on the rt blood of mice was due in part to the anesthesia employed, there can now be no doubt as to the qualitative validity of their findings.

If this marked difference in the numbers of leucocytes in the peripheral and heart blood of mice and rats is true for mammals in general, researchers should take care that they compare blood samples from the same source only. It is suggested that there may be a significant clinical difference in the leucocyte count of blood taken from patients by venipuncture and that taken by pricking the finger or ear.

The high white cell numbers in the peripheral blood as contrasted with the very low numbers in the heart blood is probably concerned with the immunity functions of the leucocyte.

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Ultraviolet Light-Absorption of Alkali-treated Solutions of Carbohydrates

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The production of light-absorbing substances by the action of alkali on carbohydrates has long been recognized. A study of the ultraviolet absorption spectra of some carbohydrates has been made by Gabryelski and Marchlewski (*1*).

We found that similar absorption was produced when starch or starch fractions were dispersed in alkali and heated. Since amylose gave much more absorption than amylopectin, it was hoped that we had found an "end-group" determination which would be a direct function

[1] The authors are indebted to several members of the Starch and Dextrose Division of this laboratory and especially to Robert J. Dimler, who supplied many of the materials necessary to this work and whose advice was indispensable.

[2] One of the laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U. S. Department of Agriculture.

of molecular weight. Later knowledge indicates, however, that under our present experimental conditions we have found a method similar to that of Schoch (*6*) for alkali lability but involving a more sensitive means of detection. The alkali lability method is a measure of the amount of alkali neutralized by acids formed in the reaction.

If there is a direct correlation between the amount of absorption produced in the alkali reaction and the molecular weights of the dextrose polymers, certain conditions must be fulfilled. These are: first, that the same absorbing group is produced in all cases; second, that the reaction occurs at an existing reducing end-group or at an end-group produced by the action of alkali; and third,

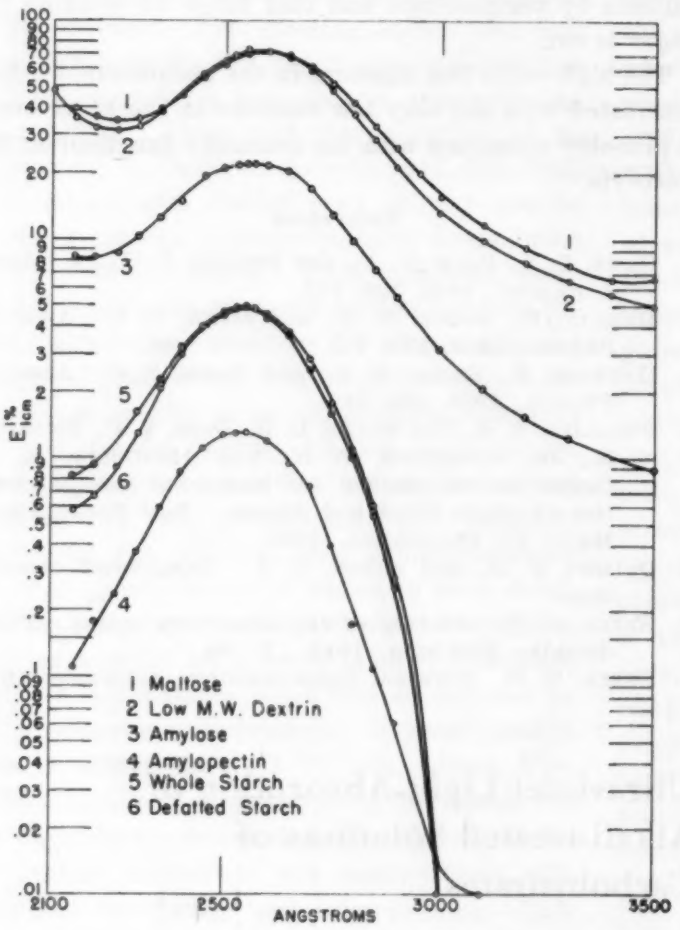

FIG. 1. Values of $E^{1\%}_{1\ cm}$ vs. wave length for starch, starch fractions and simpler carbohydrates.

that the reaction per molecule continues to the same extent in a given length of time. We have found that the first and second of these requirements are satisfied, but not the third.

A series of experiments was performed using starch and starch fractions of known history and low nitrogen content. These materials were a whole starch, a defatted starch, amylose, and amylopectin, all prepared in this laboratory from Iowa 939 hybrid corn. The starch was fractionated by the method of Schoch (*4*). For comparative purposes a number of other compounds were studied. These included maltose, a dextrin of 7 dextrose residues, cellulose, sorbitol, maltobionic acid, and Schardinger α-dextrin. Samples were heated for various lengths of time in the manner described below. Compounds which contained reducing end-groups reacted in alkaline dispersion to produce one or more compo with a strong absorption band at 2,820 A. When t alkaline solutions were exposed to air, the absorp decreased rapidly. However, if the solutions were ac fied, the peak of the absorption band was shifted 2,550 A, and the absorption did not diminish when solutions were exposed to air. To avoid reaction w oxygen, a vacuum technique was devised for the reac with alkali, and the measurements were made on acidi solutions. Typical absorption curves at the end of a 4 reaction period are shown in Fig. 1. The semilog p of absorption coefficient against wave length shows t

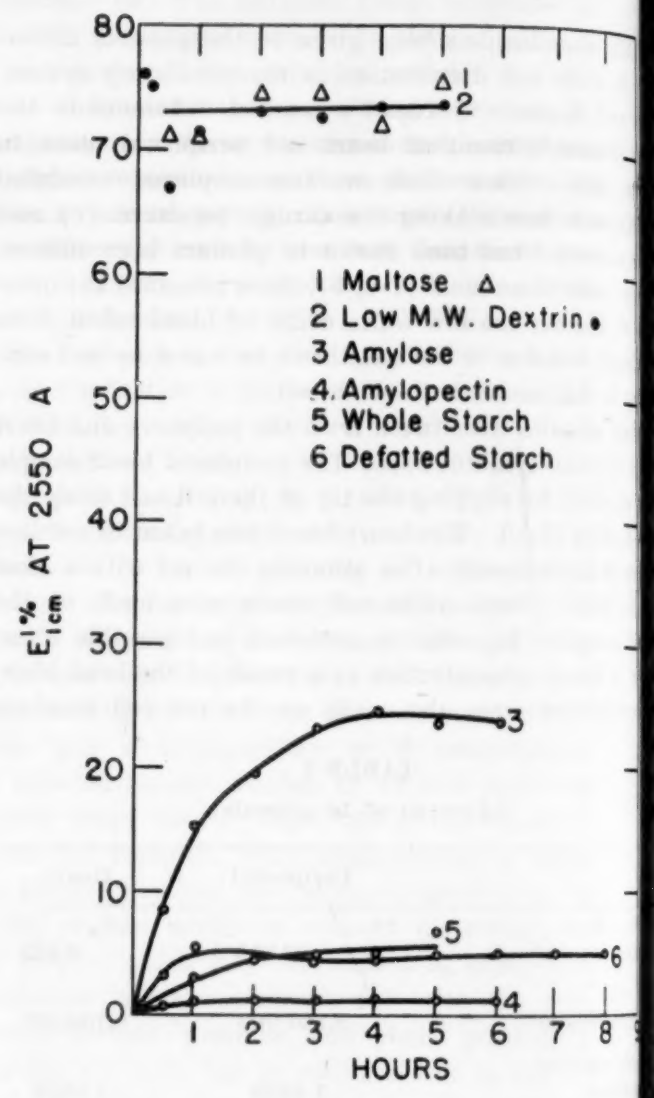

FIG. 2. Variation in values of $E^{1\%}_{1\ cm}$ at 2,550 A with reaction time.

the curves of the lower molecular weight compounds reasonably parallel. This suggests that the same abs ing group is present in the reaction products. The l of parallelism between the low-molecular-weight c pounds and the higher polymers may be attributed differences in light scattering between heated sam and unheated blanks. Thus, the first requirements st earlier is satisfied.

As we have shown, compounds with reducing groups undergo reaction to produce the characteri absorption. A number of compounds without such groups—sorbitol, maltobionic acid, and Schardi α-dextrin, which is a cyclic polymer of dextrose—do

duce the absorption. A reducing end-group is necessy to the reaction, and the second requirement is met. A sample of amylopectin was treated and after acidifition was precipitated by the addition of ethanol. The sorbing compound remained in the supernatant liquid d thus did not appear when the solid was redispersed in kali. When this alkaline dispersion of recovered amylokin was heated for a second time, no absorption develd. When the same experiment was carried out on mylose, however, as much absorption was produced by second treatment as by the first. It is evident, there-re, that the reaction is stopped by a structural difrence, possibly a branch point, in the case of amylotin. The amount of destruction resulting from the kali treatment has been estimated by following the nges produced in the optical activity of the various terials at the end of 4 hrs. In the case of maltose d the low-molecular-weight dextrin, the destruction complete, since no activity remained after the reac-. Amylose, however, retained 72% of its activity, amylopectin, 99%. Consequently, the third requirent is not satisfied, at least under the present experintal conditions.

Although no quantitative relation between the amount absorption and molecular weight has been established, is possible that other conditions or accurate knowledge the rate at which dextrose residues are destroyed could d to such a relationship.

The variation in the rate of formation of the absorbg compound is illustrated in Fig. 2. It will be noticed t with maltose and the dextrin, maximum absorption s reached in a few minutes, while nearly 3 hrs were uired for amylose. Because all the curves had leveled after 4 hrs reaction time, this period was chosen for king comparisons.

TABLE 1

Material	$E^{1\%}_{1\text{ cm}}$ at 4 hrs	Alkali number, ml 0.1 N NaOH/gm dry sample
w-molecular-weight dextrin	73.5	78
altose	72.0	78
mylose	24.3	22
mylopectin	1.3	5
hole starch	4.9	9
fatted starch	4.8	8

It is interesting that a fortuitous agreement exists tween values of $E^{1\%}_{1\text{ cm}}$ and alkali lability numbers, as own in Table 1.

If the values of $E^{1\%}_{1\text{ cm}}$ given in the table for amylose d amylopectin are used to estimate the relative molecu- sizes of these compounds, amylopectin is about 19 es larger than amylose. Actually, because the amylotin reaction is stopped at an early stage, the ratio uld be less. The literature (*2, 3, 5*) gives both larger d smaller ratios. The composition of the whole starch, lculated from the absorption values, is 84% amylopectin and 16% amylose. In several preparations, 17–20% purified amylose has been isolated from this starch, although the iodine sorption of the starch is equivalent to an amylose content of about 26%.

We intend to continue the study of the reaction of alkali with the several dextrose polymers.

The experimental procedure follows:

The sample (100 mg) for alkali treatment was placed in arm A of the reaction vessel shown in Fig. 3. The

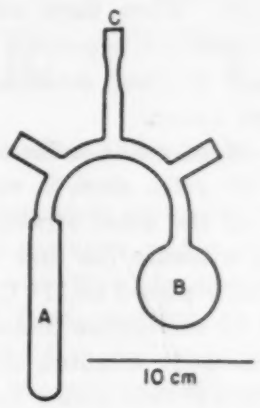

FIG. 3. Tube used in the reaction with alkali.

vessel was sealed by tube C to a stopcock leading to a vacuum line. Ten ml of 0.5 N sodium hydroxide solution was pipetted into arm B. The side arms of A and B were then sealed, and the solution in B was frozen by means of a solid carbon dioxide-alcohol bath. The system was next evacuated. (It is, of course, necessary to open the stopcock leading to the vacuum system very gently to avoid transferring a sample of starch or starch derivative out of the reaction vessel.) When the system had been pumped to a reasonably low, fixed gas pressure (about 10^{-5} mm Hg), the stopcock connecting the vacuum line and the reaction vessel was closed. To release the dissolved air, the sodium hydroxide solution was allowed to melt, was then refrozen, and the system was again evacuated to a fixed gas pressure of 10^{-6} mm Hg. After the vessel had been sealed off at the constriction in C and the solution had melted, the sample was dispersed by shaking the apparatus. The reaction was carried out by immersing the entire reaction vessel in a steam bath for the required time. The apparatus was then cooled, opened, and 2 cc of 12% hydrochloric acid was added immediately, after which the solution was transferred to a volumetric flask. When the proper dilution was reached, the ultraviolet absorption spectrum was measured against an unheated blank of the same material at the same concentration. The spectra were measured with a Beckman spectrophotometer.

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Hemolysis of Human Red Cells by Saponin Following Viral Action[1]

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Changes in human red cells, including the removal of virus receptors and the development of "panagglutinability," are produced by the action of viruses of the influenza group (*2*). When these altered human erythrocytes were subjected to hemolysis by saponin, it became apparent that another modification was produced as a result of viral action.

Shope's strain 15 of swine influenza virus (SW) was selected to alter the cells, since it removes the virus receptors for most of the other strains of influenza virus (*2*). In order to minimize the time that the human red cells would have to be placed at 37° C, the virus receptors were not removed by the elution technic of Hirst (*4*) but by the following method: Allantoic fluid of the chick embryo infected with SW was added to packed human red cells of Group O and the mixture placed in a water bath at 37° C for 2 hrs. The cells with the adsorbed virus were washed with saline, and, after removal of the supernate, a sufficient quantity of anti-SW ferret serum was added and the mixture placed at room temperature for 15 min. The cells were washed twice with 10 times their volume of saline and then made up to a 4% suspension in saline. The virus receptors were now removed from the human cells. In the lytic experiments to be described, two types of controls were employed: (1) cells treated similarly with uninfected allantoic fluid, and (2) cells whose receptors were coated with SW.

TABLE 1

Hemolysis of Virus-treated Human Red Cells by 1:15,000 Saponin

Treatment of cells	Time room temp. (min)	Photoelectric colorimeter reading			50% hemolysis
Virus receptors intact	10	0.086	0.087	0.092	0.098
	20	0.165	0.163	0.170	
	30	0.229	0.228	0.230	
Virus receptors coated	10	0.083	0.080	0.080	0.105
	20	0.150	0.168	0.168	
	30	0.223	0.235	0.232	
Virus receptors removed	10	0.106	0.106	0.107	0.122
	20	0.117	0.121	0.119	
	30	0.126	0.133	0.128	

The hemolysis resulting from the addition of 0.5 ml of a 1:15,000 dilution of saponin to 0.5 ml of a 4% suspension of the treated human red cells was determined by means of a photoelectric colorimeter. The results recorded in Table 1 show that cells whose virus recep have been removed are significantly more resistant hemolysis by saponin than are cells whose receptors intact or cells whose receptors are coated by vi There is no significant difference between the latter.

In view of the essential similarity in the action of trates of the 4Z strain of *Vibrio cholera* in remov virus receptors from human red cells, the effect of s nin on cells treated with the cholera filtrates was test The virus receptors were removed by adding the chol filtrate in borate buffer at pH 7.6 containing 0.1% c cium chloride to packed human cells at 37° C for 2 h The cells were washed twice with 10 times their vol of saline and made up to a 4% suspension in sal The virus receptors having been thus removed, the c were placed in contact with saponin and the degree hemolysis determined as above, except that a 1:18 dilution of saponin was used. The results recorded Table 2 show that cells whose virus receptors are

TABLE 2

Hemolysis of Cholera Filtrate-treated Human Re Cells by 1:18,000 Saponin

Treatment of cells	Time room temp. (min)	Photoelectric colorimeter reading			50% hem ysis
Virus receptors intact	10	0.088	0.087	0.087	0.110
	20	0.111	0.105	0.109	
	30	0.130	0.125	0.129	
	50	0.161	0.155	0.162	
	60	0.170	0.164	0.173	
Virus receptors removed	10	0.075	0.074	0.079	0.113
	20	0.084	0.082	0.087	
	30	0.096	0.092	0.095	
	50	0.113	0.113	0.118	
	60	0.123	0.120	0.127	

moved by the cholera filtrate are significantly more sistant to hemolysis by saponin than are cells wh virus receptors are intact. The cells with unaltered v receptors reached the 50% hemolytic end-point in 20 whereas cells without virus receptors did not reach same end-point until the saponin had acted on the for 50 min.

Cells whose virus receptors are removed either by v action or by the action of cholera filtrate are not m fied in their susceptibility or resistance to hemolysis hypotonic solutions. Preliminary results indicate t trypsin in a dilution of 1:100 hemolyzes cells whose ceptors have been removed more readily than cells wh receptors are intact. The fact that both virus and c era filtrate alter the resistance of human cells to he ysis by saponin is in accord with other evidence wh suggests that the modifications are induced by an enz common to the virus and the cholera filtrate (*1, 3,*

The mechanism of hemolysis is unknown. The m generally accepted theory holds that hemolysis invol the process of penetration and breakdown of a mi protein-lipoid film at the cell surface (*5*). Since the moval of virus receptors impairs hemolysis by sapo

[1] Aided by a grant from the National Foundation for Infantile Paralysis.

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the component of the red cell affected by saponin might be identical with the virus receptor. However, the action of the virus and the cholera filtrate might make more accessible an inhibitor of saponin, such as a protein or lipid.

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IN THE LABORATORY

Photograms of Small Bones and Skulls

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In work involving the comparison of small skulls and bones, especially those prepared by the alizarine-potash method, the writer found the usual photographic methods inadequate and time consuming.

Pictures with good depth of field and with definite and exact degree of enlargement were quickly and easily made by the use of a simple wooden frame in a regular condenser-equipped enlarger. Bolts were removed to separate the enlarger at the place where the negative carrier is inserted, and a black-painted wooden frame, high enough to accommodate a standard finger bowl, was fastened in place of the negative carrier. Fig. 1 shows the general

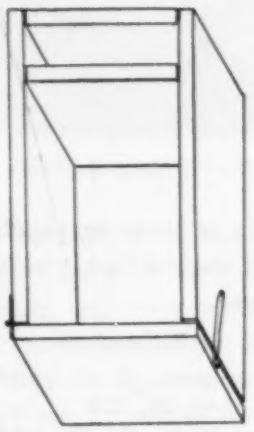

Fig. 1

plan of construction and bracing. A piece of clear glass, such as a cleaned photographic plate, was placed below it to support the specimen in its container and to avoid the possibility of spilling fluid on bellows or lens.

In use, the specimen, in a finger bowl or other suitable container partly filled with glycerine, is placed in the frame and the image focused as in ordinary enlarging. If a fair depth of glycerine is used, the specimen may be kept far enough from the bottom of the dish so that any irregularities in the latter will not be superimposed on the image. The specimen may be oriented through the opening made by the hinged part of the frame. A piece of transparent celluloid ruler, placed in the same plane in the glycerine as the specimen, will also be projected and will give the operator a ready method of determining (and recording on the margin of the print, if desired) the degree of enlargement. When orientation and degree of enlargement are satisfactory, the front part of the frame is closed and held by a rubber band, to avoid stray light, the lens stopped down to f. 16, and the exposure made on regular, normal-grade, enlarging paper. Development will result, naturally, in a white image on a black background. The thinner parts of the bones and sutures allow some light to pass, so that the resulting print, if exposed and developed for detail rather than for contrast, will have an appearance similar to that of an X-ray.

The writer and his students have found this to be a rapid and easy method, giving results much superior to those obtainable with the cameras at their disposal.

Apparatus for Partition Chromatography on Paper

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Increasing use of the methods of partition chromatography on paper (*1*) in the separation and detection of amino acids, peptides (*2–5, 12, 13*), organic acids (*11*), and sugars (*8, 9*), and the obvious applications of the method in conjunction with radioautographs (where the compounds separated by the chromatogram contain radioactive isotopes, *6, 7*), arouse interest in devices which enable the technique to be conveniently performed. A recent note by Longenecker (*10*) describes a method of making the glass troughs from which the solvents are made to flow over the paper in the manner familiar to users of this technique. In making the technique suitable for routine and quantitative work we have experimented in this laboratory with various types of troughs. The note by Longenecker prompts us to describe our solution of this part of the problem in ad-

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[2] Fellow of the National Institute of Health.

vance of a more complete statement of our procedure elsewhere.

The nature of the solvents used (phenol saturated with water and a collidine-lutidine mixture, *5*) necessitates a surface as resistant as glass. Glass troughs 30″ long and 1¾″ in diameter have proved inconvenient to make and somewhat fragile. In the search for materials from which to make troughs of the desired pattern, many possibilities were considered. Troughs constructed from plate glass, using a variety of cements, were tried. The use of certain plastic materials as well as resistant substances which could be applied as paints to troughs made from nonresistant materials were also considered. Finally, the troughs were designed with a triangular cross section (Fig. 1), and satisfactory ones (Fig. 2) were made to

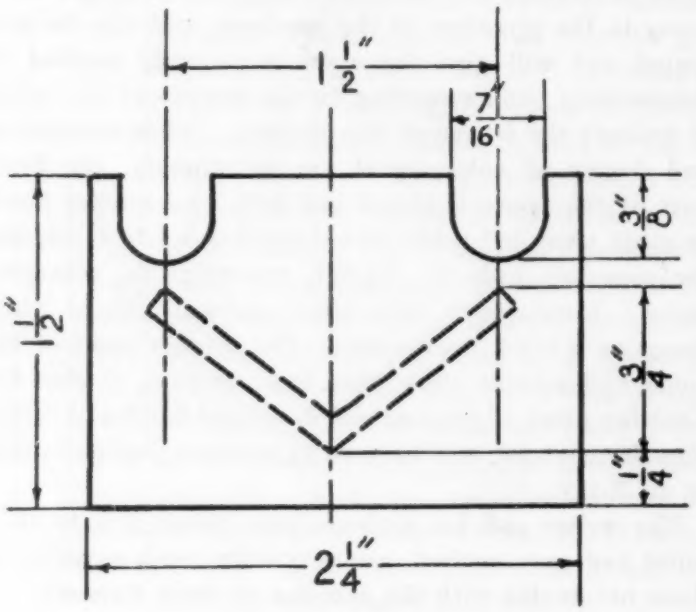

FIG. 1

specifications from sheet metal by the Pfaudler Company of Rochester, New York. The sheet metal was pressed to give the required angle (Fig. 1), and end plates were welded to the trough, the whole surface of which was thoroughly coated with a resistant enamel.

The design embodies the following features:

The V-shaped trough (34″ long) carries the solvent (70–75 ml of phenol or collidine-lutidine), into which one edge of the paper is allowed to dip.

The troughs stand upon their end plates, which also carry support for two horizontal glass rods (7/16″ or 10 mm in diameter). The latter are mounted exactly over the edge of the trough in such a way that the chromatographic paper passes over a rod and then hangs vertically but does not touch either the inside or the outside edge of the trough.

The immersed edge of the paper is held in the solvent by an overlying piece of stout glass rod, or sealed tube filled with lead shot, 7/16″ in diameter and with its ends bent at right angles to facilitate handling.

The over-all width of a trough with two papers in place is kept to the minimum (2¼″) so that the maximum number may be used in each cabinet. We now use as many as four troughs carrying 8 papers in a single cabinet about 18″ wide.

The troughs as thus constructed require no additional support, are robust and easy to clean, and, with their papers in place, are self-contained and may be placed in, or removed from, the cabinets. The enameled surfaces have proved to be completely resistant to the solvents. Care is necessary, however, to avoid chipping the enamel.

Our present large cabinets are fitted with leveling screws. The troughs, with their papers in place, are put in position in the cabinets some hours before the liquid is added. During this time the paper comes to equilibrium with the solvents (phenol-water or collidine-lutidine-water) in the cabinet. The addition of the solvent to each trough is made by pipette through a small hole in the lid of the cabinet which is then promptly closed with a stopper.

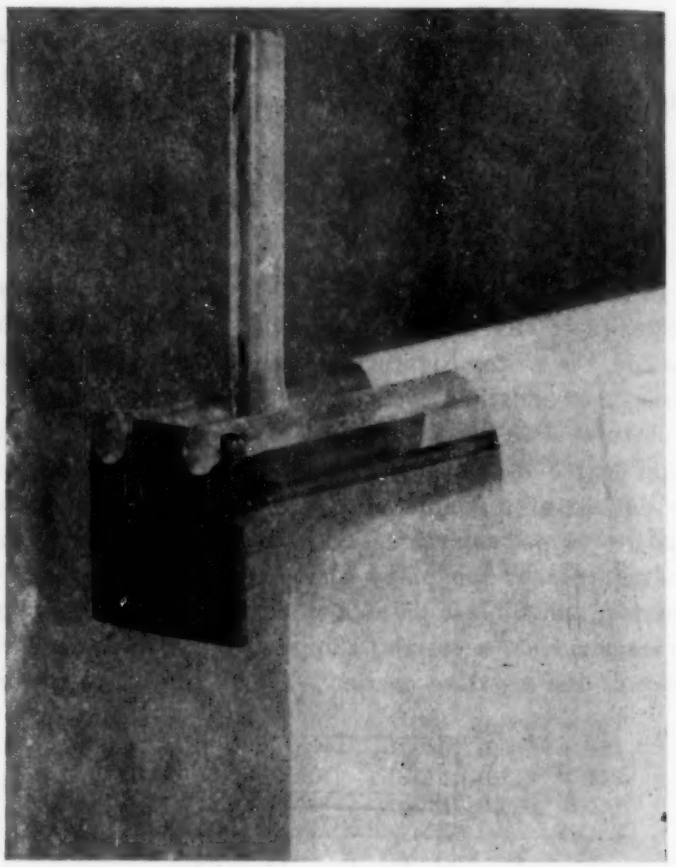

FIG. 2

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A Turbidimeter for the Measurement of the Solubility of Slightly Soluble Liquids[1]

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The measurement of the solubility of slightly soluble liquids presents some experimental difficulties. This is particularly true if the interfacial tension of the system is small and, hence, the formation of dispersions of some stability is favored.

A possible method for such determinations is the measurement of the relative intensity of light scattered by the solution under investigation as a function of the amount of solute added. As long as the solute is molecularly dispersed, only a slight degree of turbidity is observed. At

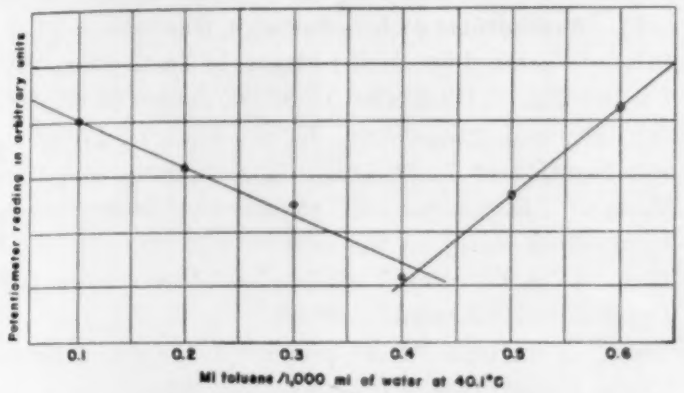

FIG. 1. Plot of the ratio of the intensities of the scattered light and the transmitted primary beam versus the volume of toluene added.

the appearance of droplets, however, a sharp increase of the scattered intensity should result. Thus, a plot of scattered intensity versus the amount of solute added should show a sharp break at the solubility limit. This is evidenced by the measurements made on a mixture of toluene and water which are represented graphically in Fig. 1.

Although several turbidimeters are described in the literature (*1–4*), an apparatus of special design, illustrated in Figs. 2 and 3, was used in our experiments.

The flask selected was a 1-liter, three-necked flask. To prevent the inclusion of air bubbles, stirring was accomplished from the bottom by means of a modified 10-ml hypodermic syringe. The end of the barrel of the latter was cut off and sealed to the bottom of the flask. To the inner end of the piston of the syringe a glass propeller was fused. The outer end of the piston was drawn out and connected to the shaft of a variable-speed motor by means of a length of rubber tubing.

The heater was made by winding 7′ of Nichrome wire around a form of asbestos and inserting it into a ½″ × 6″ test tube. A variable transformer controlled the rate of heating, while a mercury thermoregulator controlled the temperature of the solution to within ±0.1° C.

[1] This paper contains some of the material presented in partial fulfillment of the requirements for the degree of Bachelor of Arts at the University of Buffalo by James F. Coyle.

The assembly was enclosed in a wooden box, the inside of which was painted with a suspension of carbon black in lacquer in order to reduce the effect of light reflected from the walls. The primary and secondary photoelectric cells were mounted on the left side and back of the box, respectively.

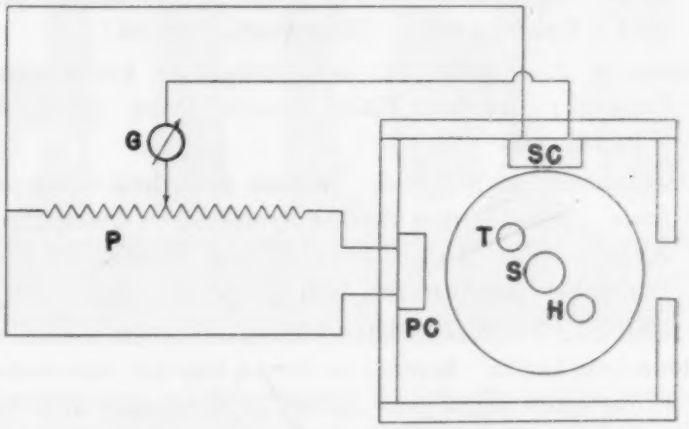

FIG. 2. Schematic representation of the electrical circuit. G, mirror galvanometer; P, potentiometer; PC, primary cell; SC, secondary cell; T, thermoregulator; S, opening for solute; H, heater.

The light source was a microscope lamp. Focusing and cooling of the light beam was accomplished by a 500-ml Florence flask filled with water.

The solute was measured and introduced through an opening in the top of the box with a 1-ml Mohr pipette.

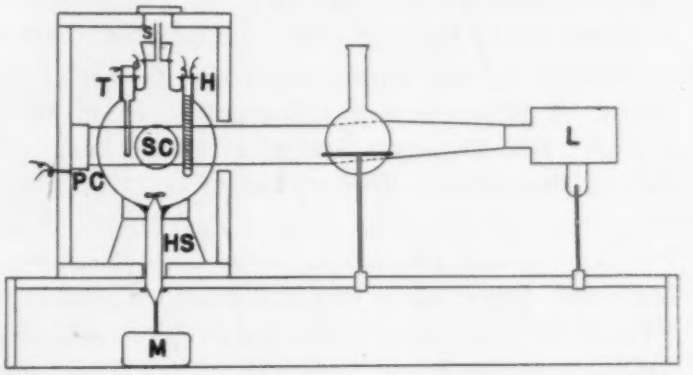

FIG. 3. Side view of the turbidimeter. S, opening for solute; T, thermoregulator; H, heater; PC, primary cell; SC, secondary cell; HS, hypodermic syringe stirrer; M, variable-speed motor; L, light source.

For the measurement of the scattered intensity a potentiometer was employed, the voltage of the photoelectric cell illuminated by the primary beam being used as a standard with which the voltage of the cell placed at right angles to it and illuminated by the scattered radiation was compared (Fig. 2).

While this turbidimeter can certainly be improved, it has proven satisfactory so far for the rapid determination of the solubilities of monomers in water and dilute soap solutions.

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